
Progress in Valve Modeling at Stennis Space Center

**R.L. Daines and J.L. Woods
Lockheed Martin Space Operations
P.R Sulyma
NASA Stennis Space Center**

**Presented at
Penn State Propulsion Engineering Research Center
14th Annual Symposium on Propulsion
December 10-11, 2002**



Stennis Space Center



Background

- Stennis – NASA center for rocket component testing
- Understanding valve behavior will aid testing
- Cryogenic liquids, gases at high pressures
 - Changes in fluid, flow conditions influence performance
 - Cavitation, transient behavior
 - Design optimization



Stennis Space Center

Outline

- Computational Model
- Cryogenic Liquid Control Valve
 - Model setup
 - Verification of calculations
 - Comparison to experiment
 - Flowfield details
- Gas Pressure Regulator Valve
 - Model setup
 - Flowfield details
- Summary



Stennis Space Center

Computational Model

- FDNS code from NASA MSFC
- Pressure-based
- Compressible/Incompressible
- k- ϵ turbulence model with wall functions



Stennis Space Center



Control Valve – Model setup

- Model performance after geometry change
- Axisymmetric
- 11 valve positions from 20% to 100% open
- Global flow characteristics normalized using valve flow coefficient:

$$C_v = \frac{\dot{m}}{\sqrt{\Delta P}}$$



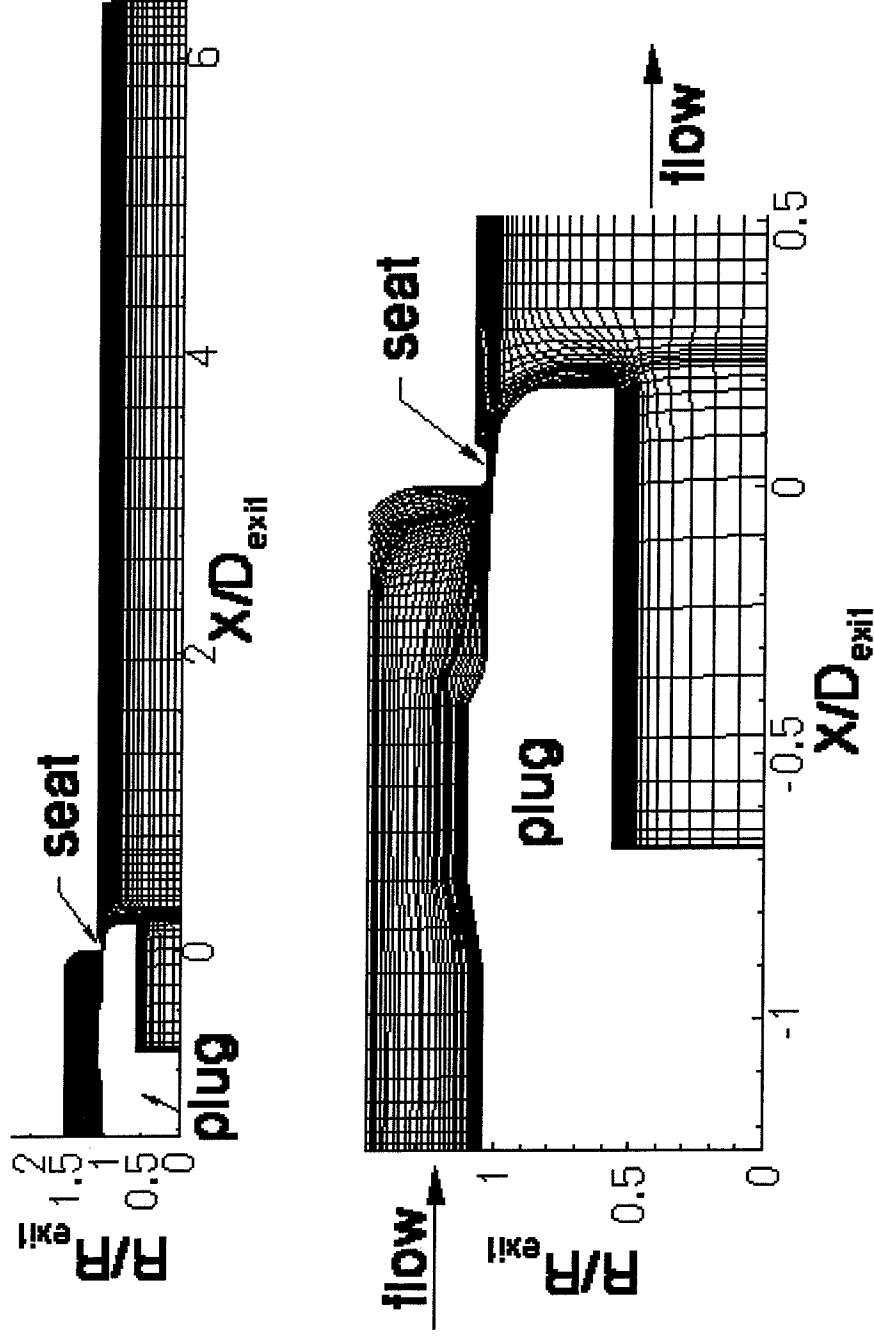
Stennis Space Center



Control Valve – Model setup

- 45% open
- 16,000 points
- $X/D \sim 6$

Computational Grid



Control Valve – Verification

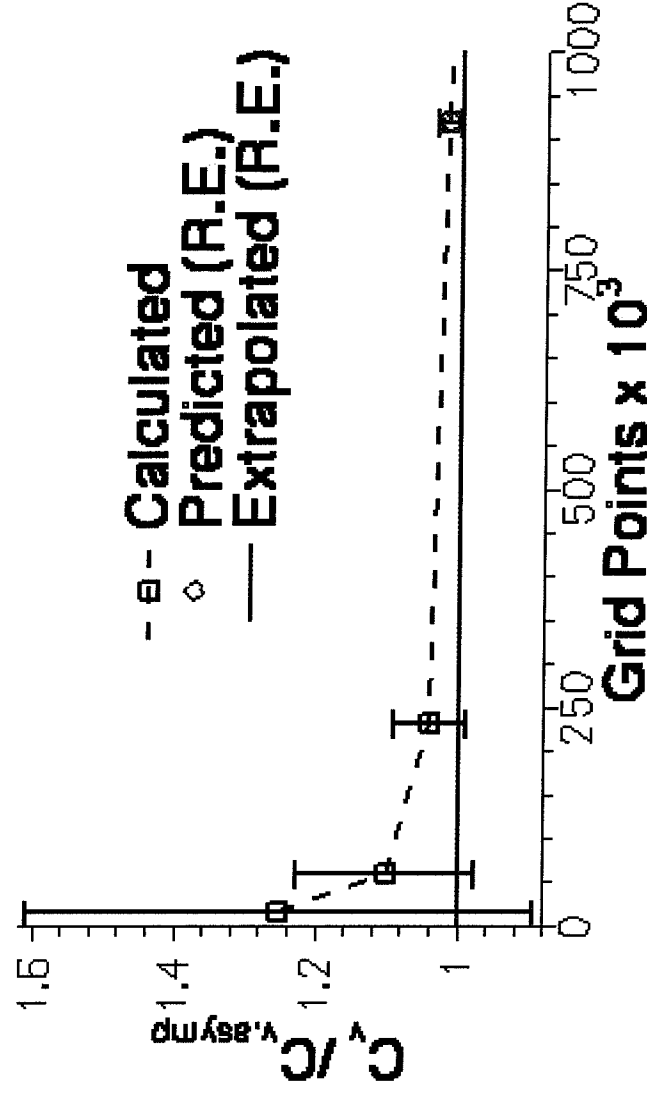
- Verification and validation important part of making valve modeling routine – confidence
- Grid doubling – 16, 60, 230 x10³ grid points
- Richardson Extrapolation
 - Order of convergence: 1.32
 - Doubling grid will reduce error by $2^{1.32} = 2.5$
 - Grid Convergence Index (GCI) – error band
 - ~10% for “medium” grid
 - Grid independent value (extrapolated)



Stennis Space Center

Control Valve – Verification

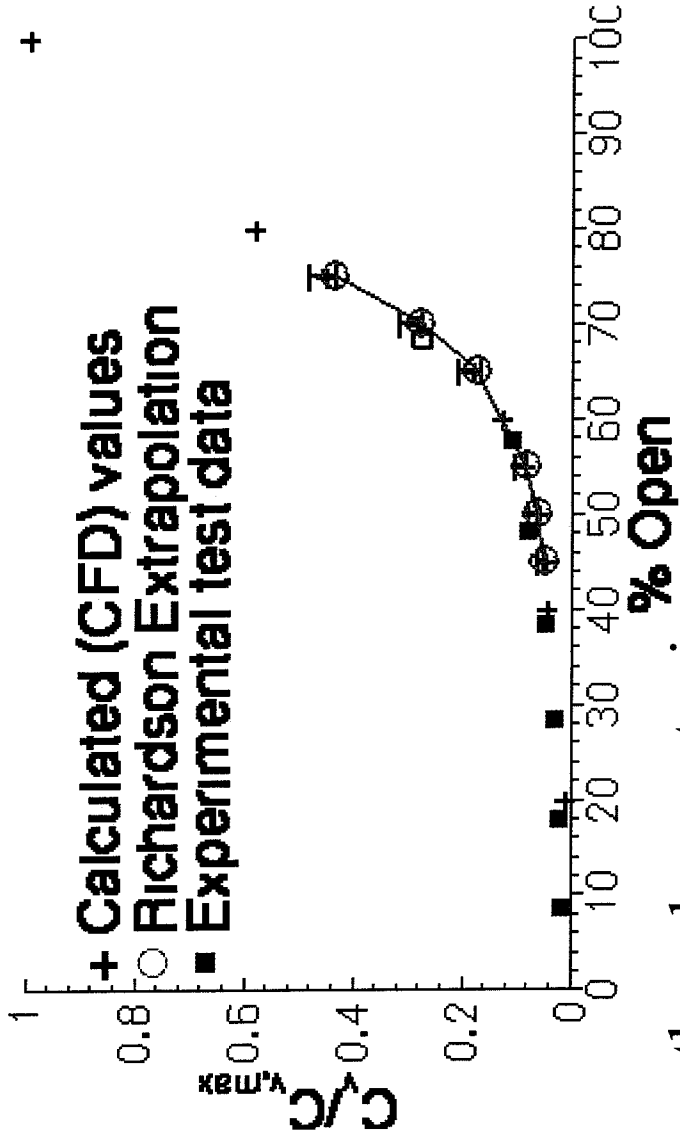
- Test of extrapolation –
 - Expected and calculated values agree to within 0.1%
- 5 other valve positions computed on “coarse” and “medium” grids
 - GCI’s range from 5.4% to 14.5%
- Use of more coarse grids & extrapolation result in significant time savings



Stennis Space Center

LOCKHEED MARTIN
Space Operations – Stennis Programs

Control Valve – Comparison to experiment



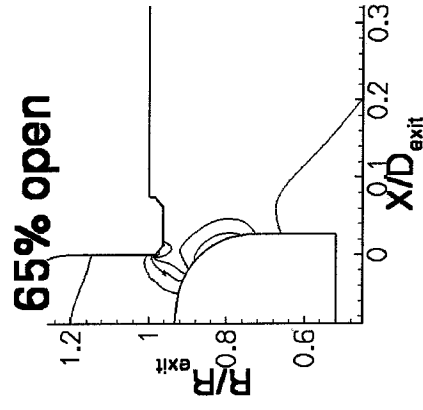
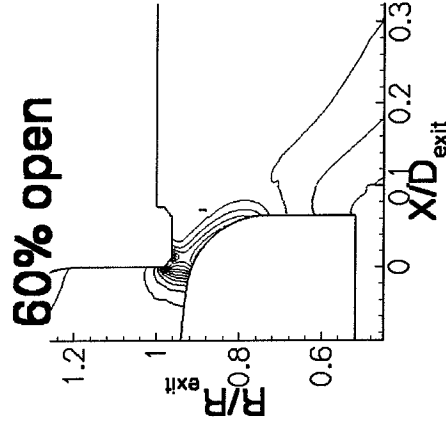
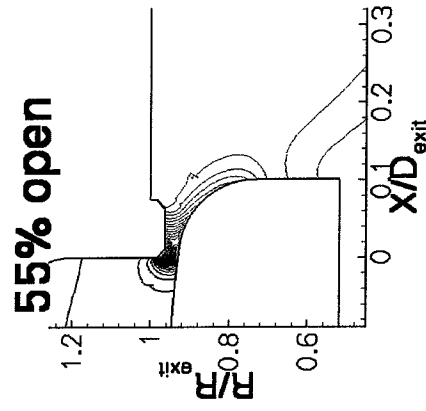
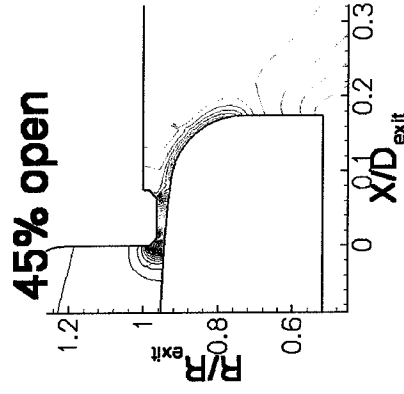
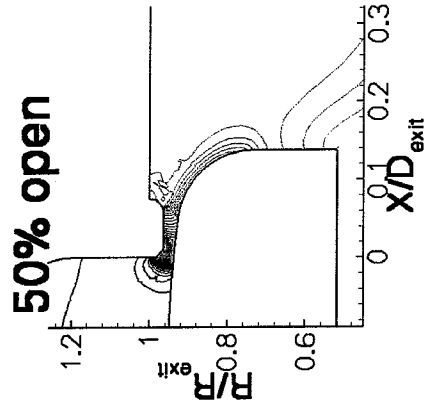
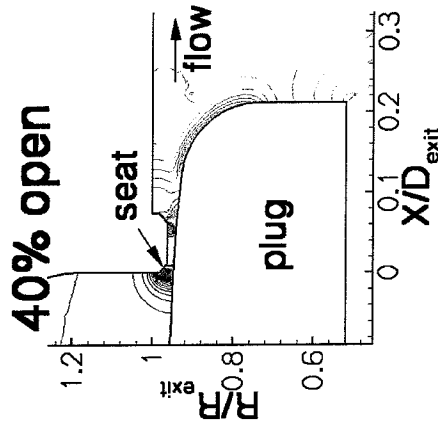
- C_v smooth and monotonic
- 7 experimental data points between 9% and 68% open
- Good qualitative agreement
- Modeling of exact experimental valve positions and experimental error bars necessary for validation



Stennis Space Center

Control Valve – Flowfield details

Pressure Contours



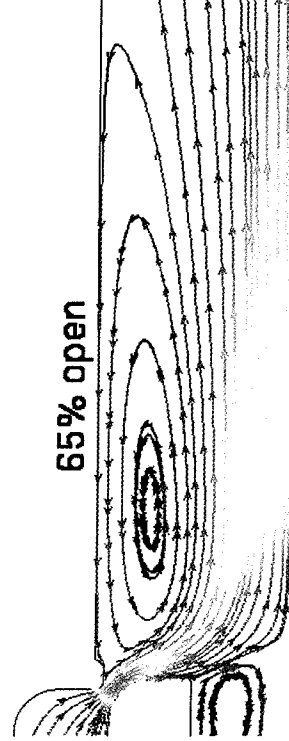
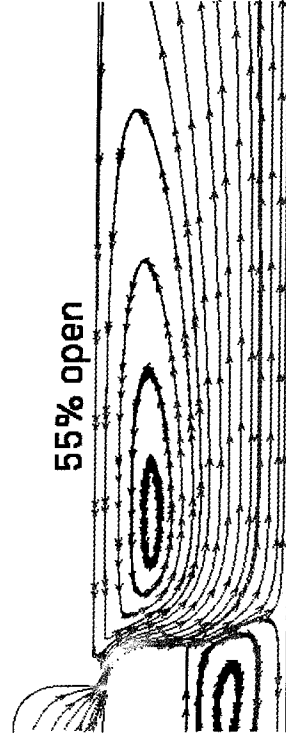
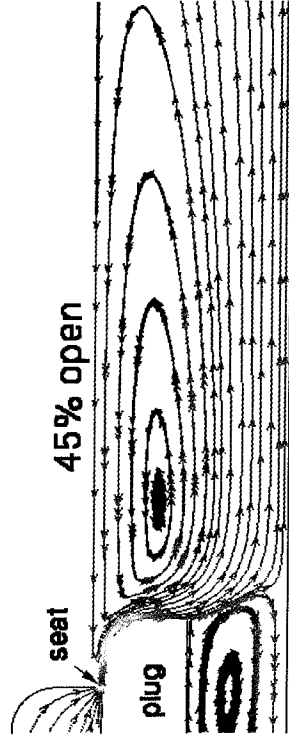
Stennis Space Center

LOCKHEED MARTIN
Space Operations – Stennis Programs



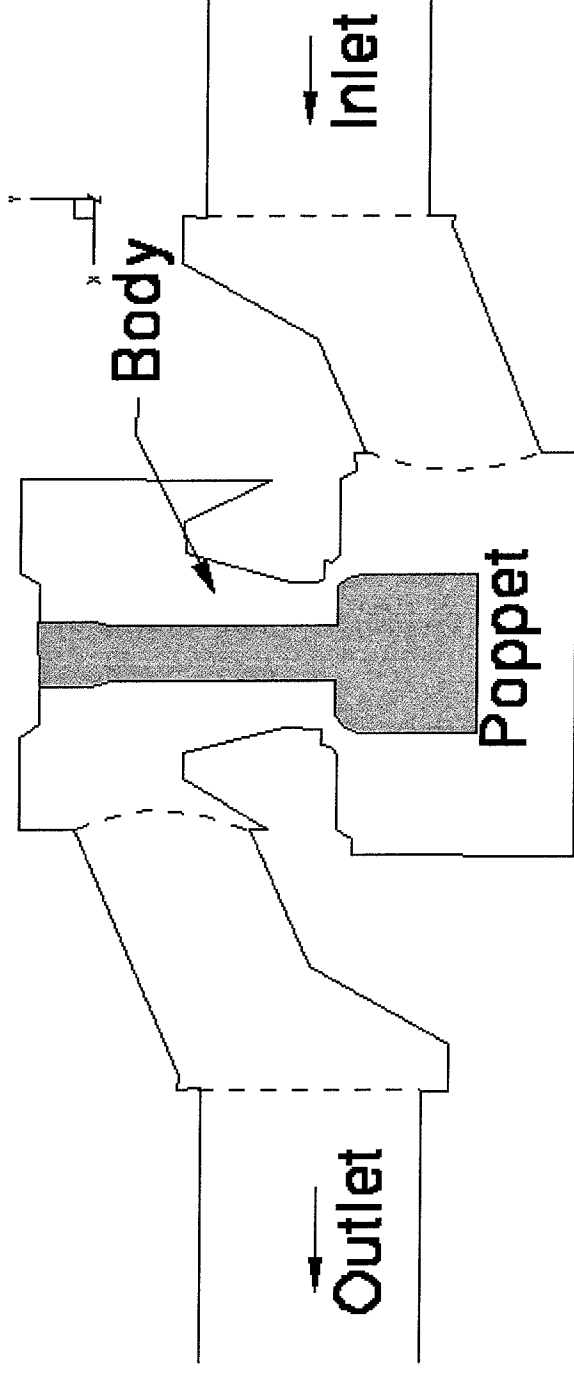
Control Valve – Flowfield details

Velocities and Streamlines



Stennis Space Center

Pressure Regulator – Model setup

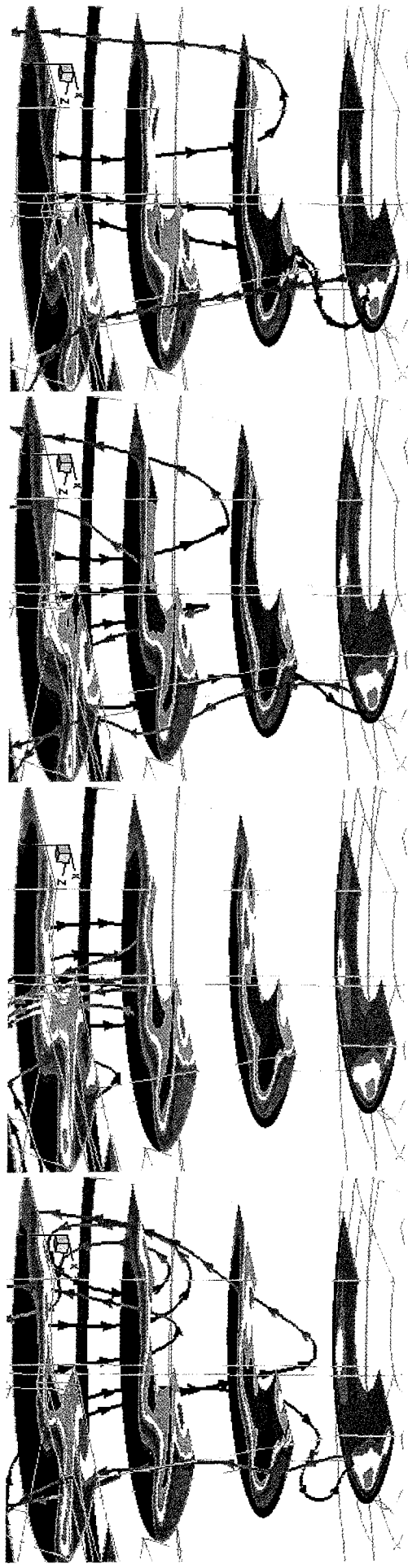


Schematic of valve cross-section

- 3-D
- High pressure helium
- Wanted to understand observed unsteady behavior
 - Constant time step of $0.1\mu\text{s}$

Pressure Regulator – Flowfield details

Velocities and streamtraces in valve body

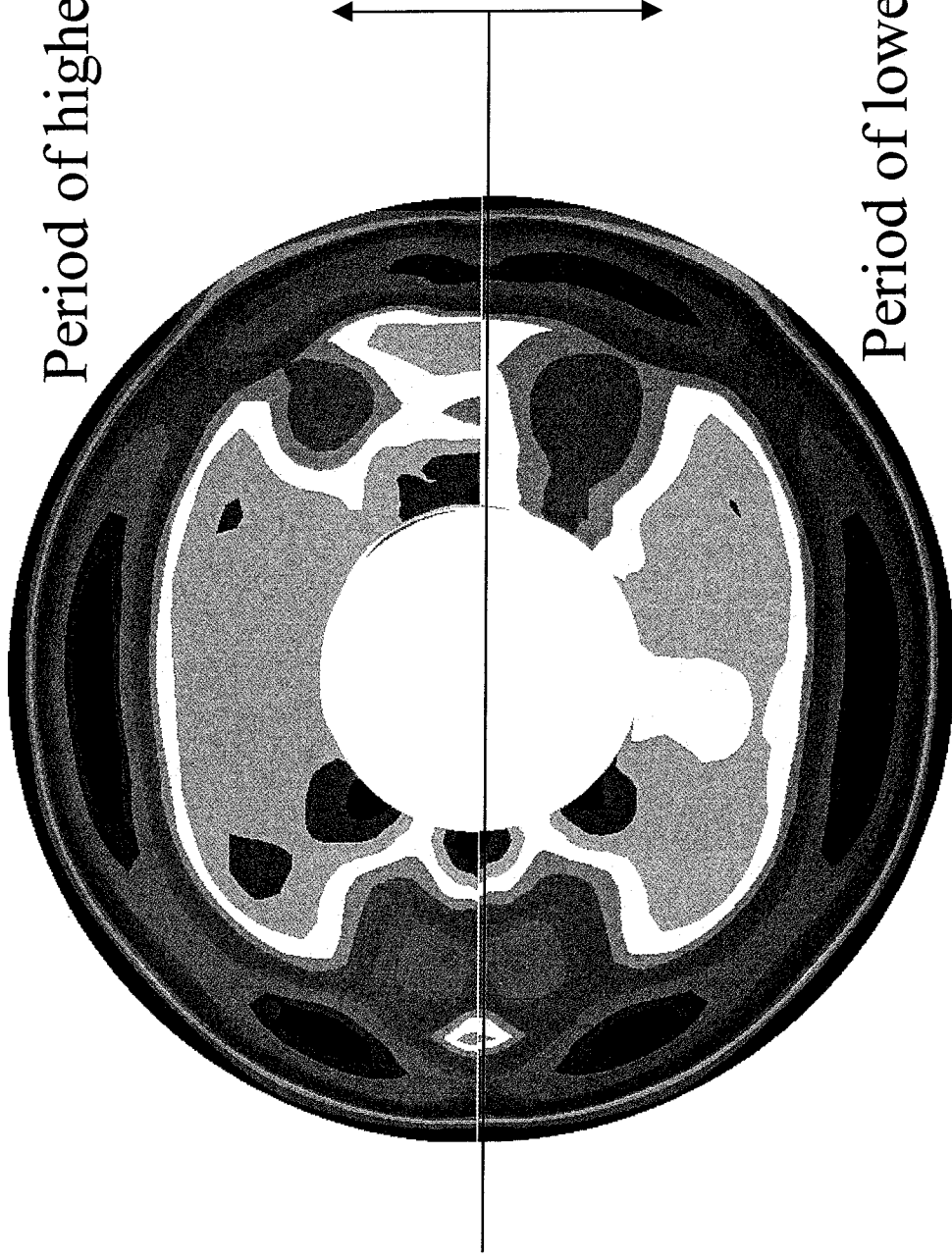


Stennis Space Center

Pressure Regulator – Flowfield details

Pressure on poppet face

Period of higher pressure



Period of lower pressure



Stennis Space Center

LOCKHEED MARTIN
Space Operations – Stennis Programs

Summary

- Preliminary work on valve modeling
 - Cryogenic liquid
 - Compressible gas
- Good qualitative agreement for liquid control valves
- Qualitative indications from gas valve model
- Verification and validation beneficial
 - Reduced run-time
 - Quantification of error



Stennis Space Center



Summary (cont.)

- Future needs
 - Unstructured capability for complex geometries
 - Real fluids treatment for cryogenic liquids
 - Cavitation
- Future Directions
 - Transient valve modeling
 - Design optimization of trim sets to tailor valves to test programs



Stennis Space Center

REPORT DOCUMENTATION PAGE					Form Approved OMB No. 0704-0188	
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.						
1. REPORT DATE (DD-MM-YYYY) 04-12-2003		2. REPORT TYPE			3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Progress in Valve Modeling at SSC				5a. CONTRACT NUMBER NAS13-650		
				5b. GRANT NUMBER		
				5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) Russell Daines Jody Woods Peter Sulyma				5d. PROJECT NUMBER		
				5e. TASK NUMBER		
				5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) LMSO - Stennis Programs					8. PERFORMING ORGANIZATION REPORT NUMBER SE- 200 -12-00081-SSC	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Program Integration Office					10. SPONSORING/MONITOR'S ACRONYM(S)	
					11. SPONSORING/MONITORING REPORT NUMBER	
12. DISTRIBUTION/AVAILABILITY STATEMENT Publicly Available STI per form 1676						
13. SUPPLEMENTARY NOTES Conference - Penn State Propulsion Engineering Research Center - Dec 2002						
14. ABSTRACT						
15. SUBJECT TERMS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT	b. ABSTRACT	c. THIS PAGE			Russell Daines	
U	U	U	UU	15	19b. TELEPHONE NUMBER (Include area code) (228) 688-3897	